Back Face Deformation (BFD) Response Comparison between KM2 and HB80 Flat Panels

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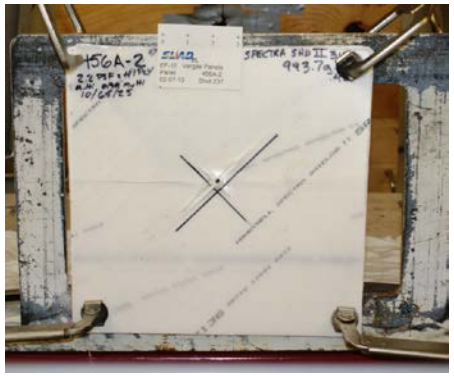
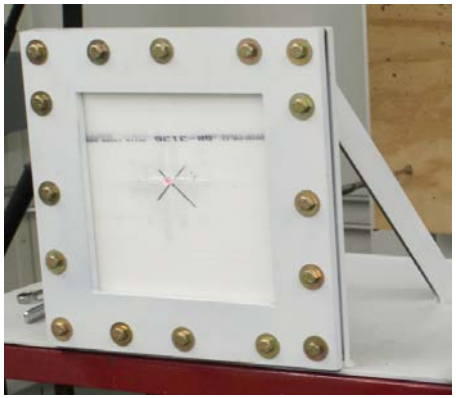
Outline

- **Background**
- **BFD experiments**
- **Numerical model**
- **Numerical results**
- **Summary**

- **Ballistic protection material**
  - Kevlar
  - Ultra-High-Molecular-Weight Polyethylene (UHMWPE)
  - V_{50} of UHMWPE is about 30% higher than Kevlar
  - BFD is equally important as V_{50}
- **Numerical models for Kevlar**
  - Delamination was not explicitly modeled

Setup





- **Digital image correlation (DIC)**
- **Boundary conditions:**
  - suspended by strings
  - four corners clamped
  - four edges clamped
- **UHMWPE and Kevlar panels**

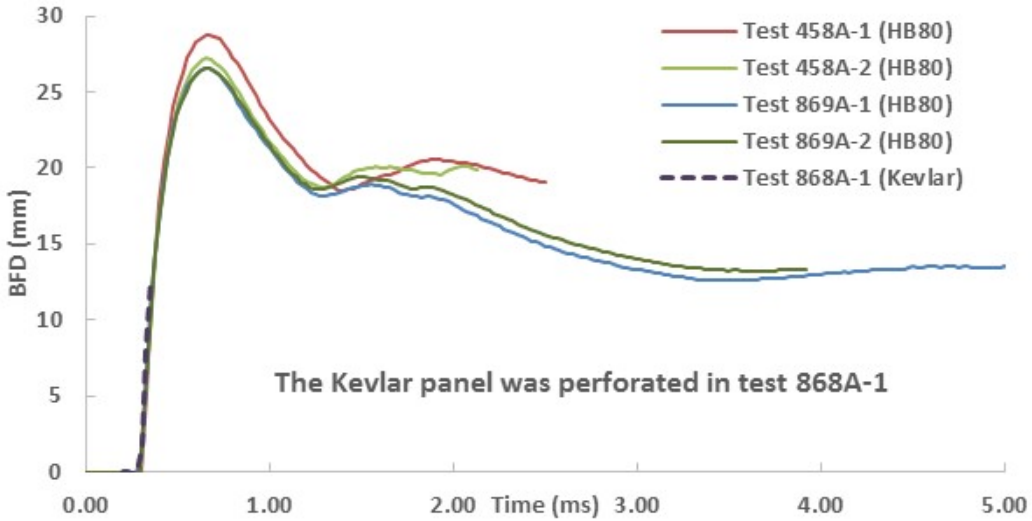
Table: TEST DATA SUMMARY FOR UHMWPE AND KEVLAR

Test	Material	Boundary Conditions	Impact velocity (m/s)	Peak center BFD (mm)	Final BFD (mm)	Normalized DOP
458A-1	HB80, [0/90]	Corner clamped	440.6	28.7	16.3	0.60
458A-2			424.1	27.3	12.7	0.50
869A-1		Free	422.1	26.6	11.7	0.53
869A-2			421.1	26.5	12.5	0.58
869A-3			307.2	18.1	8.13	0.19
869A-4			302.1	17.8	7.49	0.24
546A		Edges clamped	294.1	16.1	7.7	0.26
545A		Free	292.6	16.3	7.2	0.24
868A-1	K705, woven	Free	431.9	NA (perforated)		1
868A-2			303.4	16.6*	6.2	0.50
868A-3			297.8	15.3*	5.1	0.53
868A-4			301.1	15.5*	5.3	0.49
360B		Edge clamped	232.6	12.1	1.9	0
359B		Free	228.9	12.4	1.6	0

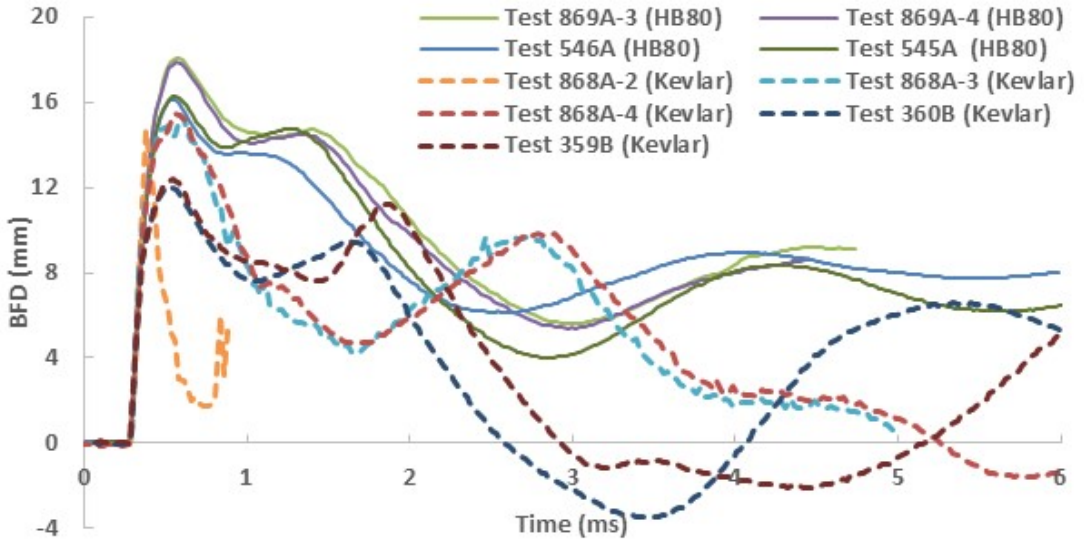
- For both Material, as the velocity drops the peak center BFD, final BFD and DOP decrease.
- The UHMWPE panels have better ballistic resistance performance.
- The peak BFD and residual BFD are lower in Kevlar panels.

Results- cont'd

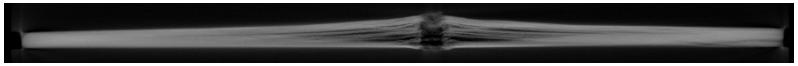
High impact speed



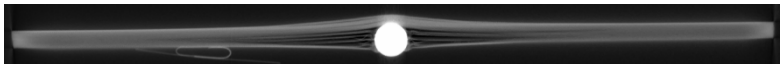
Medium impact speed



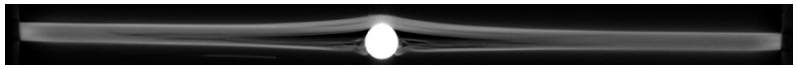
Kevlar



868A-1



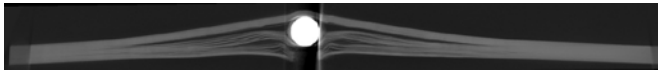
868A-3



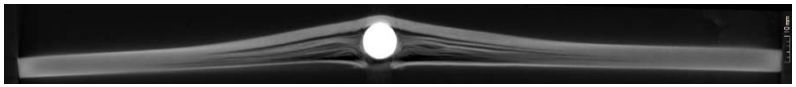
868A-4

360B

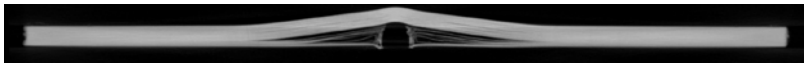
UHMWPE



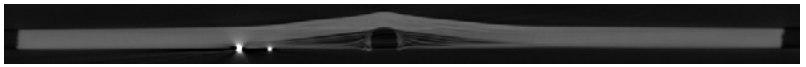
458A-1



869A-2

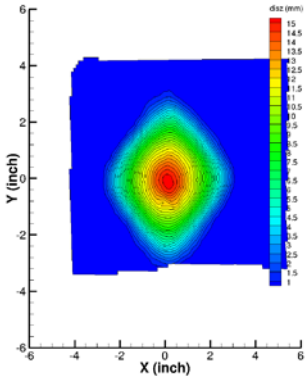


546A

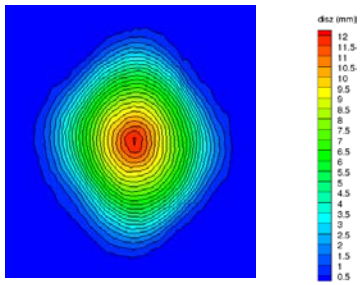


545A

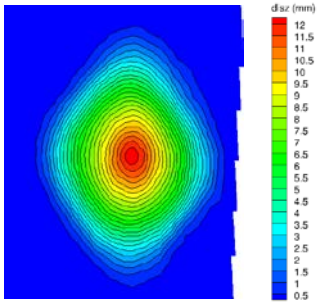
Woven K705



Test 868A-3

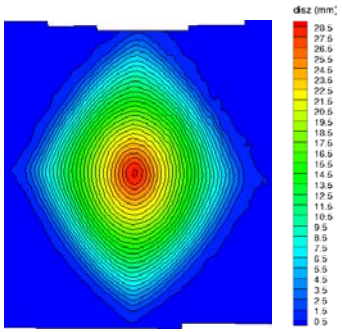


Test 360B

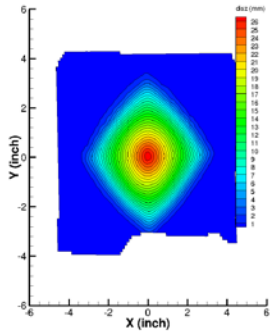


Test 359B

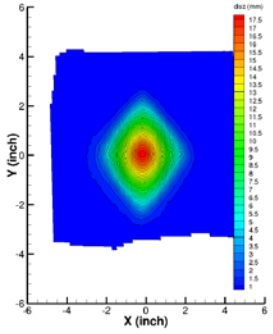
[0/90] HB80



Test 458A-1



Test 869A-2



Test 869A-4

- **Similar delamination and BFD response**
- **Same material model with different material parameters**
- **A model developed/characterized for UHMWPE was used**
  - “fused” layers
  - Two elements per layer
  - Two-zone strategy

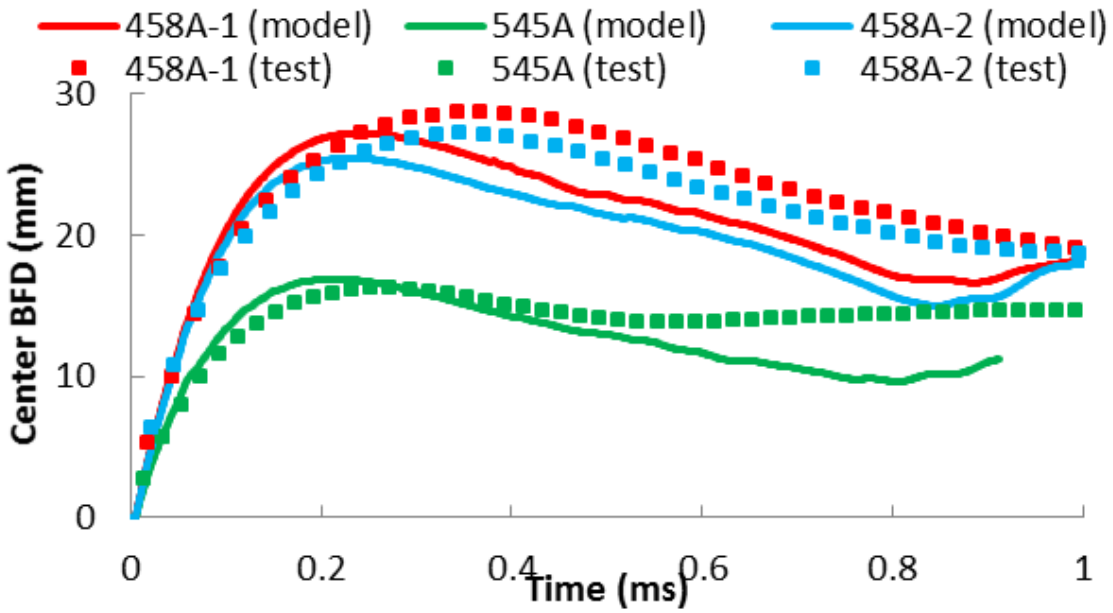


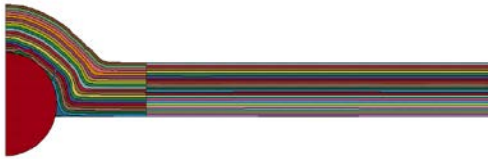
Table. Comparison between model and tests.

Test	Impact Speed (m/s)	Peak BFD (mm)			Normalized DOP	
		Model	Test	Difference	Model	Test
458A-1	440.6	27.2	28.6	5.2%	0.55	0.60
458A-2	424.1	25.5	27.3	6.7%	0.50	0.50
545A	292.6	16.9	16.3	3.6%	0.25	0.24

- **Material parameters need to be characterized**
- **Material parameters from literature were used here**

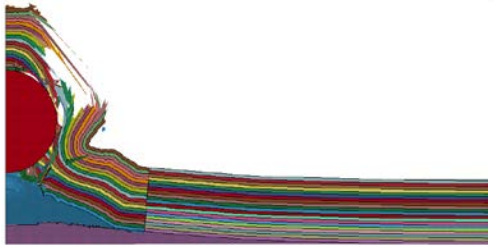
Material parameters, *from :Y. Q. Li, X. G. Li and X.-L. Gao, Modeling of Advanced Combat Helmet Under Ballistic Impact, J. Appl. Mech* 82(11), 111004 (Aug 12, 2015).

Density	ρ=1230 Kg/m^3
Young's Modulus	E_a=E_b=22GPa, E_c=9GPa
Poisson's ratio	υ_{ab}=0.25, υ_{ac}= υ_{bc}=0.33
Shear Modulus	G_{ab}=0.77GPa, G_{bc}=Gca=2.715GPa
Tensile strength	S_{aT}= S_{bT} = 800MPa
Compression strength	S_{aC}= 60MPa
Normal strength	S_{cT} = 34.5MPa
Fiber crush strength	S_{FC} =1200MPa
Fiber shear strength	S_{FS} =1086MPa
Matrix shear strength	S_{ab}=77MPa, S_{bc}=S_{ca}=898MPa
Delamination coefficient	1.2
Coulomb friction coefficient	10^o
Strain rate coefficient	C_{rate1}=0.0257, $C_{rate2,3}$=0.0246, C_{rate4}=0
Scale factor for residual compressive strength	S_{FFC}=0.3
Element eroding axial strain	E_LIMT=4.5%
Limit damage parameter for elastic modulus reduction	ω_{max}=0.9975
Limit compressive relative volume for element eroding	ECRSH=0.001
Limit expansive relative volume for element eroding	EEXPN=5.0
Coefficient for strain softening property	m_1=m_2=0.5, m_3=0.1, m_4=20



30 µs

50 µs

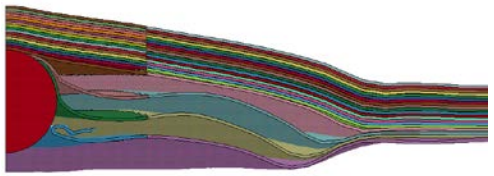


100 µs

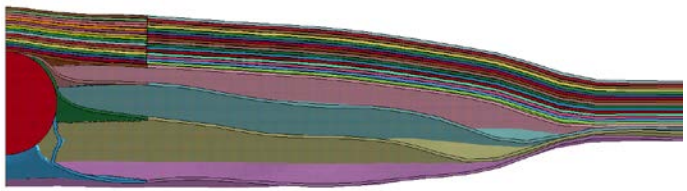
Implicit delamination model

30 µs

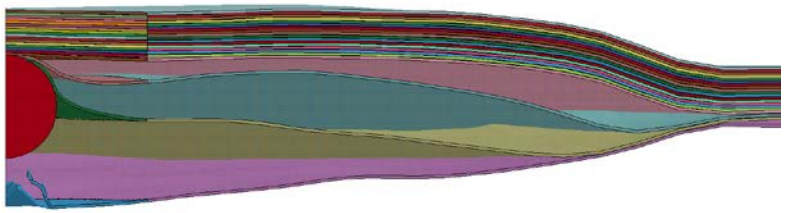
50 µs



100 µs

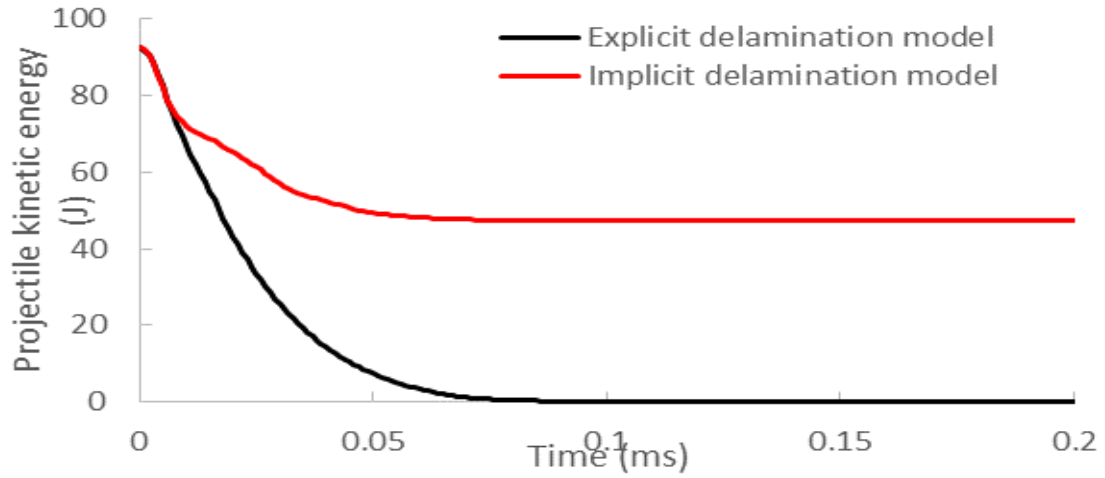


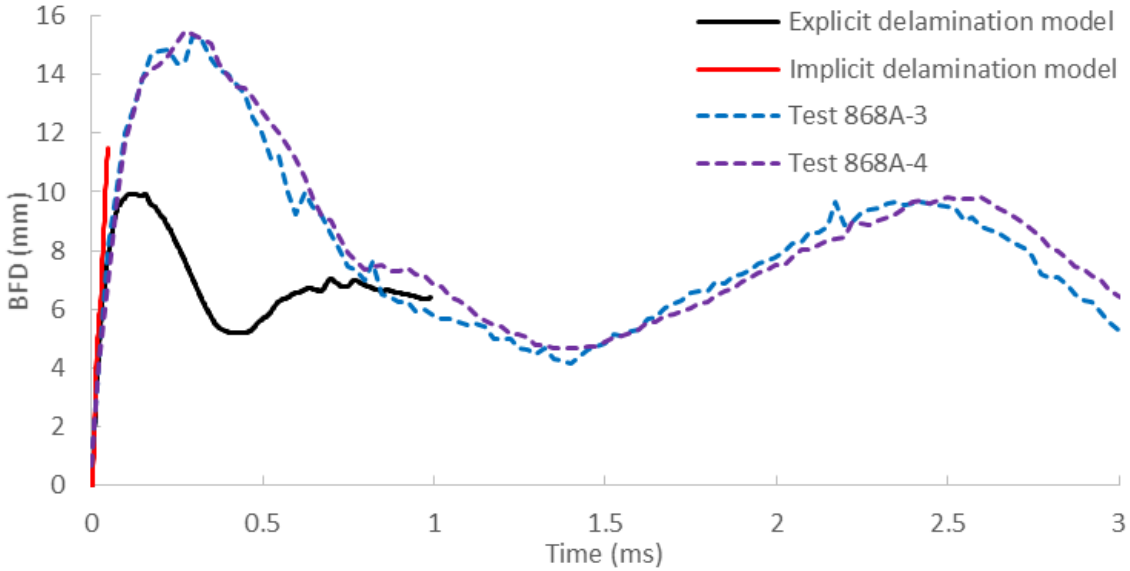
200 µs



300 µs

Explicit delamination model


Explicit delamination model
Implicit delamination model
Projectile kinetic energy (J)
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
Time (ms)


Explicit delamination model
Implicit delamination model
Test 868A-3
Test 868A-4
BFD (mm)
16
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
Time (ms)

Summary and discussion

- **Back face deformation experiments were conducted for both KM2 and HB80 flat panels**
  - the BFD was lower and the DOP was larger in the Kevlar panels
  - The BFD contours were very similar for Kevlar and UHMWPE panels and were diamond-shaped
  - Delamination along with fiber breakages were two main failure modes for both Kevlar and UHMWPE
- **A model previously characterized for UHMWPE was used to model the BFD response of both UHMWPE and KM2 panels.**
  - Model predictions agreed well with the experimental data for UHMWPE.
  - However, the model predicted lower BFD compared to the experimental data for KM2, while BFD profiles were similar.
  - The material parameters for KM2 need to be obtained by conducting material tests or characterized by the BFD test data.
  - Delamination failure needs to be explicitly modeled

Thank you!